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USE OF STATISTICAL ANALYSIS FOR CONTROLLING GLASS BATCH PREPARATION

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Some methods of statistical analysis used for controlling the quality of glass batch are examined and the factors affecting its temperature and moisture content are determined. The accuracy of the batch wetting process is determined and a cause-and-effect diagram of the instability of the moisture content of a multicomponent mixture of raw materials is constructed. It is proposed that a circular radar chart be used for analyzing the chemical composition of the glass according to the deviations of the content of the main oxides.

Key words: methods of statistical analysis, batch, temperature, moisture, control, correlating action, circular radar chart.

Batch preparation is one of the most critical processes in a glass plant, since any disruptions, starting from untimely inflow of raw materials and ending with deviations in the technology of glass batch production, are strongly reflected in the operation of glassmaking furnaces and therefore in the glass product produced [1]. For this reason, the main problem of any batch house in continuous glass production is effective control of the glass batch preparation process, which must be constructed using different schemes, methods and algorithms for correcting the batch recipe and other quality indicators that secure a constant, prescribed glass composition and stabilize the physical and chemical properties of the batch.

The following forms of such control algorithms stand out:

– compensation control based on a change of the chemical composition of the raw materials (taking account of running analysis and the predicted change of raw materials composition);

– control with feedback based on the deviation of the chemical composition of batch from prescribed values;

– control with feedback based on the deviation of the chemical composition of the glass from prescribed values;

– control with feedback based on the deviation of the density of the glass produced from prescribed values;

– combined control with disturbances compensated on the basis of a change in the chemical composition of the raw materials (with prediction) and feedback on batch composition; and,

– control of the loading and unloading of the intermediate hoppers holding batch, the batch level and holding time in the hoppers, and others.

A number of compensation and combined control algorithms, taking account of the predicted change in the chemical composition of the raw materials, batch and glass, function more effectively when using statistical analysis based on continuous (over a quite long time interval) monitoring of the main parameters of the technological process and determining the regularities of the process flow in time based on the data obtained. Statistical analysis of these data, including the raw materials batching errors, temperature and moisture content of the glass batch, the content of carbonates and sulfates in the batch, as well as the density and optical distortions of the glass and other indicators of the accuracy and stability of the glass production process [2], makes possible timely detection of different deviations arising in the batch preparation technology and adoption of pre-emptive corrective actions according to them.

For greater clarity the analysis of the control parameters that affect batch quality and the final glass product is best done using plots, histograms, control charts, tables and other easily understood and applied statistical methods, which can be used separately as well as in combinations with one another.

The most commonly used representations for statistical information are different charts making it possible not only to determine the state of a measured indicator at a definite moment in time but also to analyze the general direction of the changes, identify a trend in and seasonal fluctuations of the control parameter as well as predict a more remote result

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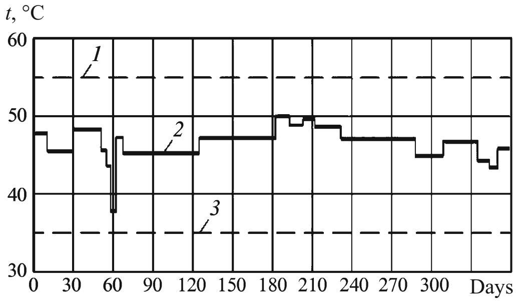

Fig. 1. Change of the batch temperature in time: *1*) upper admissible value; *2*) actual value; *3*) lower admissible value.

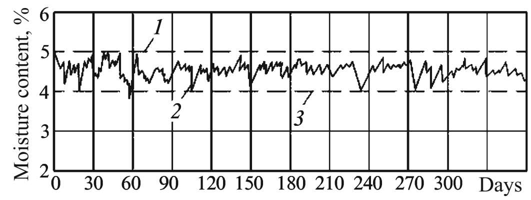

Fig. 2. Time variation of the moisture content of batch: *1*) upper admissible value; *2*) actual value; *3*) lower admissible value.

on the basis of trends in the process and validate the measures chosen to improve it [3].

For example, an analysis of the batch temperature performed in the course of one year at the AGC Borskii Glass Plant (Fig. 1) shows that batch preparation based on this parameter is quite accurate and satisfactory; a decrease or increase of the batch temperature relative to its average value 46°C is observed mainly during the winter and summer months and depends largely on the seasonal temperature variations of the cullet and raw materials stored in the dispensing hoppers and storage silos.

The temperature of the water fed into the mixer in order to wet the mixture of raw materials and the length of time the batch stays in the intermediate holding hoppers of the batch house and the transport time of the batch along an unheated gallery (7 – 8 min when using electric trolleys) have a large effect on the batch temperature. In this connection the temperature of the water, which must be hot [4], must be adjusted depending on the time of year and the temperature of the main components of the batch, while the batch is offloaded from the trolleys rhythmically without allowing it to stand motionless in prolonged intermediate storage [5]. Cold water can also be used, but in order to prevent wetted batch from drying out because of the formation of sodium carbonate and sulfate decahydrate crystals in it, which intensively bind water in the batch when the mixture temperature drops below 32°C, the batch must be additionally heated to temperature above 35°C, for which steam is fed directly into the mixer.

If the temperature of the batch during process, storage and transport is maintained at the level 35 – 55°C, the mutual effect of the temperature on the moisture content of the raw materials mixture becomes negligible, as is confirmed by the matrix of computed values of the pair correlation coefficients characterizing the close relation between the temperature and moisture content of the batch [6]. However, even though the correlation between these parameters is weak (the pair correlation coefficient is 0.14) it is necessary to take account of the general destabilizing factors affecting the temperature and moisture content of the multicomponent mixture. Statistical analysis of the moisture content of the batch performed at the AGC Borskii Glass Plant during a similar period of time as the batch temperature monitoring shows (Fig. 2) that primary factors are the seasonal variations of the ambient temperature and the fluctuations of the moisture content of the glass batch components, especially the hygroscopic materials (soda, saltpeter, sulfate).

There are other factors causing the moisture content of batch to deviate from the computed values (4.5 ± 0.5%). For example, studies have shown that when the water in the storage tank was heated by steam injected directly into the interior of the liquid by means of special injectors the water became saturated with a large number of micro-bubbles, which briefly destabilized the operation of the batching system and decreased the real water flow when the wetting pumps were switched on for a prescribed period of time. All this, including fluctuations of the grid voltage about 380 V, rare malfunctions in the control system and the software of the automatic process control system as well as other factors associated with equipment failures in the batching and mixing lines, degrades the accuracy of the glass batch wetting process.

The accuracy of this technological process during the period of monitoring can be evaluated using the relation

$$K_{\text{T}} = 6S_X/\Delta X = 6 \times 0.167/1.0 = 1.0,$$

where K_{T} is the coefficient of accuracy of the technological process, $S_X = 0.167$ is the standard deviation, and $\Delta X = 1.0$ is the admissible interval of deviations of the moisture content of the batch.

For computed values of the coefficient of accuracy greater than 0.98 the accuracy with which the moisture content of the batch is maintained is considered to be unsatisfactory (the process is considered to be accurate if $K_{\text{T}} \le 0.75$) [7]. In this case all reasons for the decrease of this quality index of the batch must be determined and the appropriate measures of controlling and adjusting actions must be taken.

In the cases where it is difficult to find all reasons for the disruption of the technological process of glass batch preparation the method proposed by Kaoru Isikawa in 1953 is used [8]. This method, which is based on constructing a cause-effect diagram or an Isikawa diagram, is widely used in Japan and is characterized as a process of interaction of the four M's: Material, Machine, Man (Operator) and Method.

The construction of such a diagram, called "fish bone" (sometimes "fish skeleton," "tree" and so on), includes

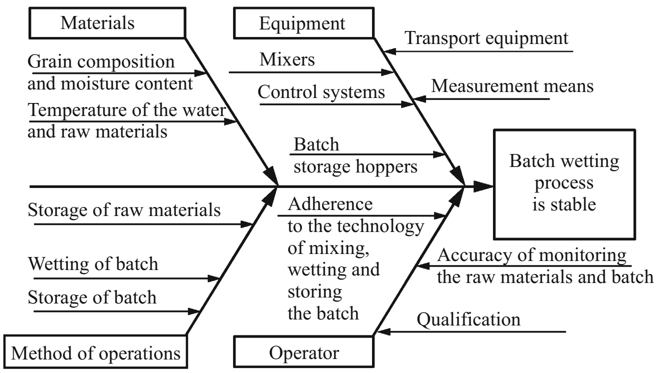

Fig. 3. Cause-effect diagram of the instability of the batch moisture content.

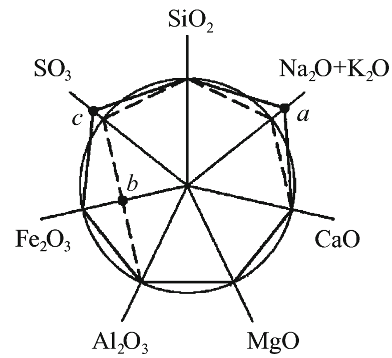

Fig. 4. Circular radar chart of the oxides content in the glass.

choosing the batch quality indicator to be analyzed, establishing the main reasons influencing the indicator ("large bones of the fish skeleton") and determining the secondary and tertiary factors having to do with the characteristic under study ("medium and small bones").

We shall examine the construction of the cause-effect diagram for analyzing the factors influencing the deviation of the batch moisture content which exceed the tolerance field (Fig. 3). Possible factors are: the quality and moisture content of the raw materials, state of the process equipment, differing operator skill levels, accuracy in the satisfaction of the process rules, method of implementing the operations and other reasons, often requiring additional study.

When the "fishbone" diagrams are used to investigate these reasons it is sometimes possible to bring in third parties who have no direct relation to the work of the batch house, because an unexpected solution for modernizing the equipment, normalizing the control process and eliminating the rejects in batch production could occur to them. In addition, together with the cause-effect diagram it is also helpful to use Pareto diagrams, which make it possible to clarify the essence of the phenomenon with respect to each concrete types of defects or deviations found in the course of the analysis of the statistical observations.

One other type of graphical representation of the statistical information on batch and glass quality is the circular radar chart, which makes it possible to evaluate the accuracy of the technological process with respect to deviations of the chemical composition. It is convenient to make a comparative assessment of these deviations, characterizing an excursion beyond the upper and lower limits of the percentage content of the main oxides in the glass, using the corresponding points whose position on the scale rays emanating from the center of the circular chart is calculated using the following relations [9]:

$$R_i^{\mathrm{ul}} = 1 + (n_i^{\mathrm{ul}}/n_i); \quad R_i^{\mathrm{ll}} = 1 - (n_i^{\mathrm{ll}}/n_i)$$

where R_i^{ul} is the position of the point in the chart reflecting the excursion of the ith oxide beyond the upper admissible limit; R_i^{ll} is the position of the chart point reflecting the excursion of the ith oxide being the lower admissible limit; n_i is the number of measurements of the content of the ith oxide in the glass; n_i^{ul} is the number of measurements where the content of the ith oxide exceeded the upper admissible limit; and, n_i^{ll} is the number of measurements where the content of the ith oxide in the glass exceeded the lower admissible limit.

The results of calculations performed with these relations using the data from laboratory measurements (more than 300 measurements in the production of sheet glass were performed) are presented in Table 1.

The number of scale-rays in the circular chart in the example considered (Fig. 4) is seven and corresponds to eight main oxides in sheet glass (Na_2O and K_2O are combined into one group). The computed positions of the far and

TABLE 1. Results of Calculations Performed with the Relations Presented

Oxide	SiO_2	Na_2O+K_2O	CaO	MgO	Al_2O_3	Fe_2O_3	SO_3
Content, %	72.6	13.4	8.7	4.0	0.9	0.1	?0.3
Admissible deviation, %	±0.2	±0.1	±0.1	±0.1	±0.1	±0.015	–
Excursion above the upper admissible limit n_i^{ul}/n_i	0	0.16	0	0	0	0	0.12
Excursion beyond the lower admissible limit n_i^{ll}/n_i	0	0	0	0	0	0.38	0
Position of the far point on the chart R_i^{ul}	1	1.16	1	1	1	1	1.12
Position of the near point on the chart R_i^{ll}	1	1	1	1	1	0.62	1

near points are noted on the scales of the radar chart and connected by solid and dashed lines, forming two polygons. The points outside the circle of unit radius indicate that the percentage content of the oxide pertaining to it exceeds the admissible upper limit, while the fraction of analyses with such an excursion is characterized by the segment of a straight line on the ray which is a continuation of the radius of unit length. So, the position of the far point *a* for the oxide sum $Na_2O + K_2O$, determined by the value $R_i^{ul} = 1.16$, means that approximately 1/6-th of the glass produced in one year had an elevated content of alkali-containing components, so that it is necessary to pay attention to the work of the soda and sulfate batchers. The identical assessment of the position of the near point *b* in the chart calls attention to the low Fe_2O_3 content, which is also inadmissible, because a decrease of the iron oxide content during operation of the tank in the glass furnace results in an increase of the diathermancy of the glass and can entrain into the production flow crystalline inclusions from the bottom layers of the molten glass and increase rejects of the finished product.

In summary, the use of different methods of statistical analysis and regulation in the production of sheet glass makes it possible to improve the technological process, determine the dependence of the batch quality indicators on the most important factors responsible for the appearance of rejects, and increase the control efficiency on the basis of the results of an analysis of the statistical data on the controlled process.

REFERENCES

1. R. I. Makarov, E. R. Khorosheva, K. Yu. Subbotin, and V. V. Efremenkov, “Statistical methods of monitoring and regulating in the technological process of preparing batch for the production of sheet glass,” in: *Economics and Education in Economics* [in Russian], Vladimir (2005), Part 1, pp. 29 – 30.
2. R. I. Makarov, E. R. Khorosheva, K. Yu. Subbotin, et al., “The effect of the batch preparation process on batch quality,” *Steklo Keram.*, No. 4, 42 – 43 (2005); R. I. Makarov, E. R. Khorosheva, K. Yu. Subbotin, et al., “The effect of batch preparation technology on its quality,” *Glass Ceram.*, **62**(3 – 4), 121 – 122 (2005).
3. R. I. Makarov, V. V. Tarbeev, E. R. Khorosheva, et al., *Control of Sheet Glass Quality (Float Method)* [in Russian], Assotsiatsiya Stroitel’nykh Vuzov, Moscow (2004).
4. N. A. Pankova and N. Yu. Mikhailenko, *Glass Batch and Its Preparation* [in Russian], ITS RKhTU im. D. I. Mendeleeva, Moscow (1997).
5. V. V. Efremenkov and K. Yu. Subbotin, “Optimization of the batch load in a glassmaking furnace,” *Steklo Keram.*, No. 10, 17 – 18 (2006); V. V. Efremenkov and K. Yu. Subbotin, “Optimization of batch charging in the glass furnace,” *Glass Ceram.*, **63**(9 – 10), 334 – 335 (2006).
6. V. V. Efremenkov and K. Yu. Subbotin, “Statistical methods of monitoring and regulating in the glass batch preparation process,” *Steklo Keram.*, No. 5, 3 – 5 (2006); V. V. Efremenkov and K. Yu. Subbotin, “Statistical control methods in glass batch preparation process,” *Glass Ceram.*, **63**(5 – 6), 39 – 141 (2006).
7. V. I. Gissin, *Control of Product Quality* [in Russian], Feniks, Rostov-on-Don (2000).
8. S. D. Il’enkova, N. D. Il’enkova, V. S. Mkhitrayan, et al., *Quality Control* [in Russian], Banki i Birzhi, YuNITI, Moscow (1998).
9. E. R. Khorosheva, A. V. Molodkin, and V. V. Efremenkov, “Application of circular radar charts in the analysis of the accuracy of a technological process,” in: *Proc. 3rd Inter. Sci.-Tech. Conf. on New Methods of Designing Article for Microelectronics* [in Russian], Vladimir (2004), pp. 135 – 137.